ALTERATION OF CIGARETTE SMOKE COMPOSITION II. INFLUENCE OF CIGARETTE DESIGN[1]

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BY J. H. TERRELL and I. SCHMELTZ,
Houdry Laboratories, Air Products and Chemicals, Inc., Linwood, Pa., U.S.A., and Eastern Utilization Research and Development Division, ARS, U. S. Department of Agriculture, Philadelphia, Pa., U.S.A.

Experimental data are presented which illustrate the effect of cigarette fabrication methods and materials on the level of combustion products in the mainstream smoke gases. As the length of the unconsumed cigarette becomes shorter, the concentration of combustion products in the smoke gas increases.

The porosity of the cigarette paper is a primary factor which contributes to the dilution of components in the mainstream gas. Measured burn temperatures were observed to be slightly lower (△28°C) for cigarettes fabricated with high porosity paper. Measurable differences in the composition of the smoke gas have also been observed with changes in the permeability of the cigarette wrapper.

INTRODUCTION

Previous reports by the authors (1,2) and by others (3,4) have shown that certain additives to cigarettes modify the composition of cigarette smoke. These compositional effects may arise from changes in combustion processes and/or changes in burn temperature induced by the additive (5). The objective of the study (2) was, through the use of such additives, to remove substances from the vapor phase of cigarette smoke which may be detrimental to health (2).

During the course of our work with additives, it was noted that certain factors, related to the physical design of the cigarette, affected concentration levels of vapor phase constituents in cigarette smoke. Although not new (3,4), our observations were considered significant, in that they indicated that by modifying such parameters as porosity of the cigarette paper, length of cigarette and others, one could effect greater changes, more conveniently, in the vapor phase of cigarette smoke than by the use of additives. In addition, the observations suggested that some of the effects noted with some additives may have been due, in large measure, to the way these additives were intermixed with the tobacco, and the resulting orientation of tobacco fibers and additive within the cigarettes.

In the present report, we show how changes in certain aspects of cigarette design affect smoke gas composition.

EXPERIMENTAL

The fabrication of cigarettes and their characteristics, the smoking apparatus, methods of smoke collection, sampling and analytical techniques have been described in the previous paper (2).

In the present report, control cigarettes refer to commercially obtained, filterless (85 mm.) cigarettes. All test cigarettes were fabricated from tobacco which had been removed from the control cigarettes. Variation in the fabrication testing included the use of a different grade of cigarette paper, modifications to the paper, change in cigarette length, and a change in the packing of the tobacco fibers. The test cigarettes (85 mm.) were fabricated in the laboratory from "new" cigarette paper, and from tobacco (thoroughly mixed) taken from the commercial cigarettes (2).

RESULTS AND DISCUSSIONS

When tobacco was removed from commercial cigarettes, thoroughly mixed, and used to fabricate new cigarettes with a different grade of paper, the resulting cigarettes were observed to burn at lower temperatures (△28°C) and produce lower levels of combustion products than their commercial analogs. The lower burn temperature was calculated from average burn temperatures measured for over 100 cigarettes of each type. It was also observed that the cigarettes which were fabricated in the laboratory took longer to burn to a 30 mm. butt length. Measured burn time for the test cigarette was 11.04 minutes as compared to 8.22 minutes for the control cigarette. These effects were believed to be due to a change in the draw of air through the refabricated cigarettes brought about by 1) the use of more porous cigarette paper, or 2) the reorientation o fthe tobacco fibers in the refabricated cigarettes.

To investigate further the effect of draw on burn temperatures and smoke composition, cigarettes, were prepared in varying lengths from 50-150 mm. and tested. Burn temperature measurements (**Table 1**) and smoke analysis (vapor phase, **Table 2**) showed that while there was little change in burn temperature with changes in cigarette length, there was significant change in the levels of certain cigarette smoke con-

Table 1. Effect of cigarette length on the cigarette burn temperature.

	Length, mm	Burn Temp., °C
Control cigarette	85	849
Control cigarette	50	847
Test cigarette	50	818
Test cigarette	85	821
Test cigarette	100	829
Test cigarette	150	799[a]
Test cigarette with double paper	85	851

[a] *Average of 782 and 816 degrees, C.*

[1] *This study was carried out under contract with the Agricultural Research Service, United States Department of Agriculture, administered by the Eastern Utilization Research and Development Division, 600 East Mermaid Lane, Philadelphia, Pennsylvania, 19118, U.S.A.*

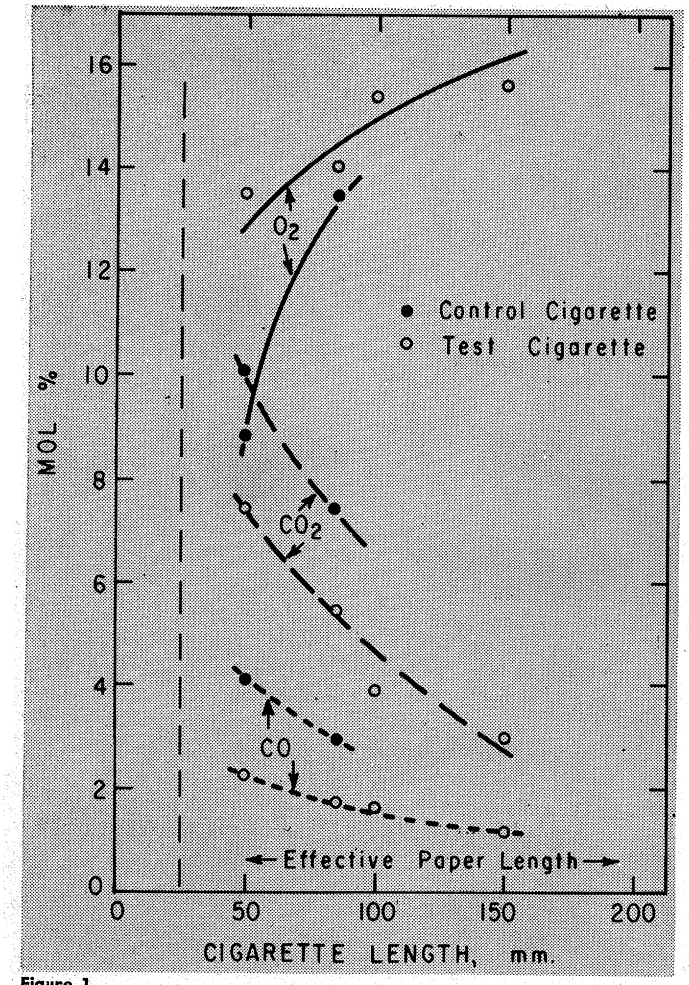

Figure 1.

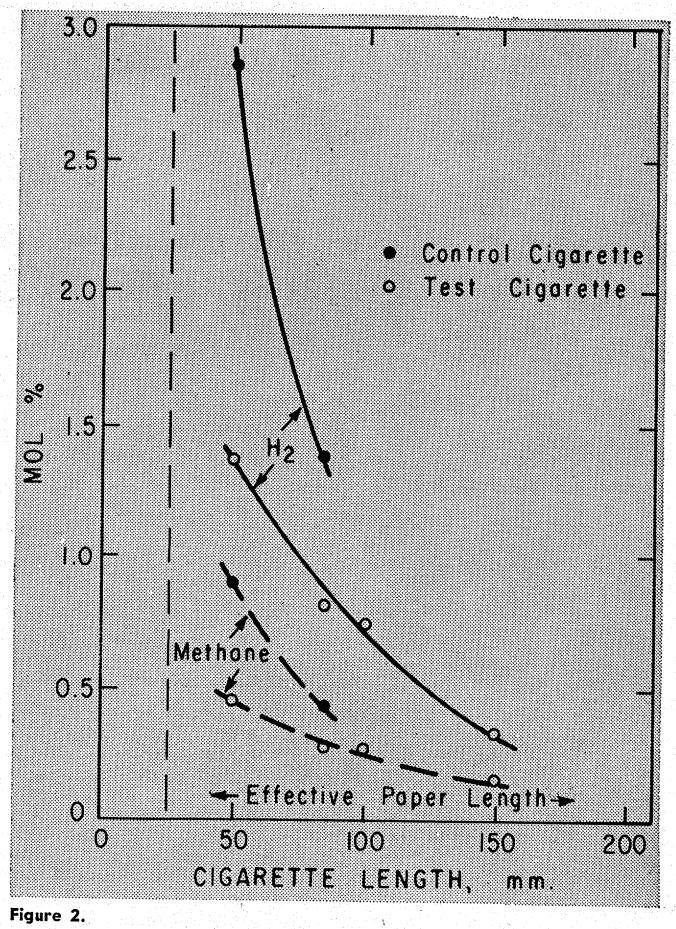

Figure 2.

stituents. The levels of all constituents which were determined decreased, with the exception of oxygen. with increasing cigarette length. Inasmuch as their relative proportions appeared to remain, more or less constant, it seemed likely that these constituents were being diluted with air drawn through the length of the cigarette paper (6), and/or channeled between the burning cone and the paper. It is interesting to note that the burn temperature as well as the level of combustion products of the test cigarette (85 mm.) modified by encasement in an additional layer of cigarette paper was in good agreement with the control cigarette.

The data showing the relationship between cigarette length and levels of certain smoke constituents are presented graphically in **Figures 1-3.** Extrapolation of the data to an "unusually" long cigarette indicates that at lengths of 250 mm. (or greater) the gas drawn through the cigarette might consist of air and tobacco volatiles only. At this point (250 mm.), negligible air would be drawn through the burn cone; the cigarette should be free-burning even during puffing at the mouthpiece.

On the other hand, the concentration level of components in the vapor phase produced from an "infinitely" short cigarette might be similar to that from a cigarette wrapped with nonporous paper, e.g., sealed with cellophane tape of diethylene glycol (**Table 3**). Extrapolation of the curves in **Figures 1-3** to a cigarette length of 25 mm., for example, should give concentration levels of vapor phase constituents when porosity effects are at a minimum. (In the present instance, a length of 25 mm. was chosen to represent minimum porosity because all analyses were made on the fifth puff which was 15 mm. from the lit end of the cigarette; in addition, a length of 10 mm. was confined within the Cambridge filter holder. In **Figures 1-3**, an effective paper length is thus noted.) If a cigarette is examined as a whole, rather than on the basis of a single puff, it follows, therefore, that the dilution effect should be minimized as the cigarette becomes shorter (i.e., is smoked "down"). Such an effect is illustrated in **Table 4.** When the cigarette becomes shorter, the concentration level of combustion

Table 2. Effect of cigarette length on the composition of cigarette smoke gases.

		Mol %						
		H_2	O_2	CO	CO_2	Methane	Ethane	Ethylene
Control	(50 mm)	2.86	8.80	4.11	10.10	0.90	0.1117	0.0564
	(85 mm)	1.38	13.46	3.00	7.43	0.43	0.0805	0.0389
Test	(50 mm)	1.37	13.50	2.30	1.45	0.46	0.0814	0.0394
	(85 mm)	0.82	14.01	1.78	5.46	0.28	0.0489	0.0244
	(100 mm)	0.76	15.41	1.65	3.91	0.28	0.0463	0.0210
	(150 mm)	0.33	15.69	1.08	3.04	0.15	0.0319	0.0149

Table 3. Effect of cigarette paper porosity on the concentration of components in cigarette smoke.

		Mol %						
Cigarette (85 mm)	Burn Temp °C	H_2	O_2	CO	CO_2	Methane	Ethane	Ethylene
Control	849	1.38	13.46	3.00	7.43	0.43	0.0805	0.0389
Control (Cellophane tape 40 mm)	832	2.72	8.83	4.94	10.43	0.55	0.1229	0.0606
Control (Diethylene glycol)	817[a]	3.48	7.36	5.10	13.23	0.94	0.1470	0.0835
Control tobacco plug in lab paper	—	0.87	13.61	1.98	—	0.27	—	—
Test	821	0.82	14.01	1.78	5.46	0.28	0.0489	0.0244
Test (Double paper)	851	1.16	13.78	2.24	7.39	0.37	0.0914	0.0419

[a] *Free burn—no puff spike*

products becomes greater. Differences in the values obtained with the control cigarette and the test cigarette reflect differences in the porosity of the cigarette paper (vide infra).

That the porosity of the cigarette paper played a significant role in the dilution of smoke components with air was demonstrated by modifying cigarettes to reduce the porosity of the paper. For example, when commercial (85 mm.) cigarettes were sealed with cellophane tape for 40 mm. of their length (25 mm. from the lit end) and then smoked (on a smoking and smoke collection apparatus), there resulted a significant increase in levels of combustion products in the smoke gas and corresponding decrease in the oxygen content (**Table 3**). This effect was even more pronounced when the cigarette paper was impregnated with diethylene glycol (**Table 3**). The data are interpreted to suggest that in addition to sealing the cigarette paper, the channels between the paper and the tobacco were also sealed, thus producing much less dilution than was observed with the cellophane tape. In addition, a test cigarette fabricated with a double rather than single layer of cigarette paper also produced a marked increase in the quantity of combustion products in the smoke gas (**Table 3**). Moreover, when the tobacco from a commercial cigarette was removed carefully as a plug, rerolled in the "test" cigarette paper, and the resulting cigarette smoked, lower values (**Table 3**) for levels of hydrogen, methane and carbon monoxide were obtained. Thus, the change in cigarette paper grade was primarily responsible for the lower level of combustion products.

Further evidence that the concentration level of components in the smoke gas is influenced by the porosity of the cigarette paper is illustrated in **Table 5** where cigarettes with perforated cigarette papers are shown to produce considerably less combustion products than their unperforated analogs. It is suggested that perforation of the filters of filtered cigarettes would give similarly low yields of components in the vapor phase. However, as noted by the nonproportional change in some of the components listed in **Table 5**, other factors such as absorption of the smoke constituents by the tobacco, followed by recombustion or pyrolysis may govern the choice of perforating the paper of the filter.

CONCLUDING REMARKS

This report and the one (2) preceding it have demonstrated that the composition of the vapor phase of smoke can be influenced by the use of combustion modifiers (2), and by changes in the physical design of the cigarette. Specifically, the most significant factor affecting the level of combustion products in cigarette smoke is apparently the extent to which air can infiltrate the cigarette paper or channel between the burn cone and the paper; this infiltration (or channeling) may be regulated by changing the porosity of the cigarette paper, by changing the effective length of the cigarette, or by reorienting the packing of the tobacco within the cigarette. An equivalent effect could be achieved by the insertion of holes in either the paper, or in the filter of filtered cigarettes. It may be argued that, whereas, higher permeability of the cigarette wrapper produces lower concentrations of some constituents in the smoke gas and a corresponding increase in the number of puffs required to "smoke down" the cigarette, the quantity of any constituent in the total mainstream smoke gas would remain unchanged. That this is not necessarily so is demonstrated by calculating a total yield of some

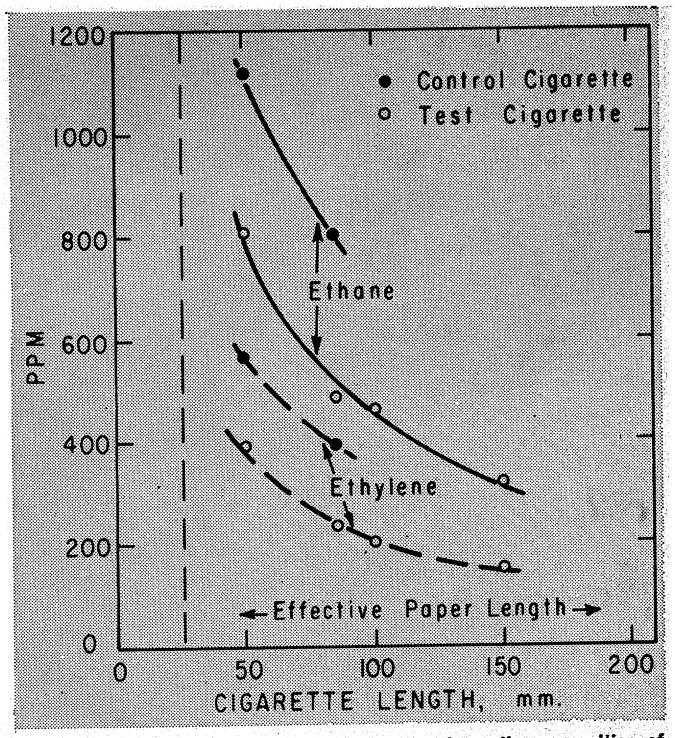

Figure 3: Figures 1-3—Effect of cigarette length on the composition of cigarette smoke.

selected constituents based on the analysis of the fifth puff and the total number of puffs: control cigarette —0.86 ml. of carbon monoxide and 84.7 micrograms of acrolein; test cigarette—0.68 ml. of carbon monoxide and 62.9 micrograms of acrolein in the mainstream smoke gas. While adsorption and/or pyrolysis may be responsible for these differences, it is of interest to note that a similar calculation based on the last puff from each type of cigarette also indicates a lower total yield of carbon monoxide from the test cigarette.

In addition to a general increase in the concentration of components in the gas phase, with decreasing cigarette length, some changes are also noted in the specific composition of the gas. For example, the ratio of carbon monoxide to hydrogen or methane increases as the length of the smoke path becomes shorter (7,8,9).

Although no data were obtained during this study on the effect of air infiltration on levels of particulate

Table 4. The composition of smoke gases for control and reference cigarettes smoked at butt lengths of 70 mm and 30 mm.

	Butt length	Mol % H_2	O_2	CO	Methane
Control cigarette	70 mm	1.38	13.46	3.00	0.43
Control cigarette	30 mm	2.62	10.57	3.84	0.71
Test cigarette	70 mm	0.82	14.01	1.78	0.28
Test cigarette	30 mm	1.38	12.68	2.64	0.45

Table 5. Effect of perforated[a] cigarette paper on the composition of cigarette smoke gases.

	Mcg/35 ml puff			
	Control		Test	
	Without holes	With holes	Without holes	With holes
Methanol	36.1	18.3	24.1	24.6
Acetaldehyde	74.0	35.0	46.9	11.0
Acetonitrile	14.3	8.7	12.8	2.8
Acrolein	9.2	7.1	5.7	2.3
Acetone	40.6	40.6	27.0	8.1

[a]*Eight pin holes (2 rows of four each along the length of the cigarette).*

matter, nicotine, benzo(a)pyrene and phenol in the smoke it seems reasonable that the levels of these materials would also decrease with increasing length of the cigarette and increasing porosity of the cigarette paper. Schur and Rickards (10) have shown that higher permeability of the cigarette paper results in lower "tar" yield, and changes in smoke composition with changes in the porosity of the cigarette paper have been indicated by Lipp and VanNooy (6).

SUMMARY

Changes in the composition of the vapor phase of cigarette smoke were effected by changing certain physical parameters of a cigarette—such as length of cigarette, and porosity of cigarette paper. In general, these changes were instrumental in regulating the quantity of air infiltrating the cigarette and in most favorable instances produced dilution of smoke gas components. The cigarettes modified to give less air drawn through the combustion zone gave measurably lower average burn temperatures as well as a greater number of puffs.

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